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# THE OKCR AND PILOT PERFORMANCE DURING TRANSITIONS BETWEEN METEOROLOGICAL CONDITIONS USING HMD ATTITUDE SYMBOLOGY

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## ABSTRACT

Research has shown that spatial disorientation often occurs when pilots transition between real-world visual cues and head-down attitude instruments. Recent studies investigating the opto-kinetic cervical reflex (OKCR) indicate that when pilots transition between these two types of visual cues, they are also transitioning between frames of reference. Limited research has been conducted investigating pilots' response during transitions between real-world visual cues and helmet-mounted display (HMD) attitude symbology. Eleven pilots performed vertical "S" maneuvers in and out of clouds to simulate frequent transitions between visual meteorological conditions and instrument meteorological conditions using both primary flight symbology on an HMD and traditional head-down primary flight instruments. Because pilots focused primarily on the symbology during the task, the OKCR was not found. Results also revealed that pilots were better able to maintain commanded vertical velocity when using the HMD compared to the head-down instruments, which is attributed to the head-up location of the symbology. Having the HMD symbology superimposed on the real-world visual scene can provide additional visual cues that pilots can use to perform their task more efficiently.

## INTRODUCTION

In spite of all of the latest technological advances incorporated into today's modern fighter aircraft, spatial disorientation (SD) in flight continues to be a problem. SD is, in general, pilots' inability to accurately interpret the attitude of their aircraft with respect to another aircraft or to the earth. For the past three decades, the percentage of accidents attributed to SD has remained relatively constant. Gillingham and Wolfe (1985) and Benson (1988) report that the problem of SD is often caused by the transition from visual meteorological conditions (VMC), when pilots use real-world visual cues to fly, to instrument meteorological conditions (IMC), when pilots have to use instruments to fly. In addition, a recent investigation of SD episodes among F-15C pilots during Desert Storm showed that *the* contributing factor to these types of incidences was visual transition from looking outside the cockpit to inside the cockpit and vice versa (Collins and Harrison, 1995). Based on these reports, it appears that there is a lack of continuity between real-world visual cues and the representation of these cues in the cockpit.

This lack of continuity between the two types of visual cues may be directly related to the frame of reference within which attitude information is portrayed. There are generally two frames of reference that have been used to portray aircraft attitude – an aircraft frame of reference and a world frame of reference. The aircraft frame of reference portrays the aircraft as the fixed entity while move-

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ment and orientation of other objects around it are used to determine aircraft orientation. A world frame of reference portrays the world as the fixed entity with objects moving within it.

Traditional head-down attitude instruments and head-up displays (HUDs) portray attitude information in an aircraft-referenced way. Since the current trend is to display HUD symbology on helmet-mounted displays (HMDs)(Bailey, 1994), it too will portray aircraft-referenced symbology. In contrast, when pilots see real-world visual cues, they interpret their aircraft orientation by determining the position of their aircraft against a fixed horizon, thus using a world-referenced system (Gillingham and Wolfe, 1985; Grether, 1947; Roscoe, 1992). The previous statement is supported by a documented head-tilt phenomena studied originally by Hasbrook and Rasmussen (1973) and later by Patterson (1995). Both studies showed that pilots were subconsciously aligning their heads with the horizon. Patterson hypothesized that pilots were trying to maintain a clear retinal image of the horizon while the aircraft maneuvered, and were using the horizon as their primary visual cue for determining orientation (Patterson, 1995). He termed this head-tilt response the opto-kinetic cervical reflex (OKCR).

When pilots flew in VMC, Patterson found the OKCR, however, when pilots flew in IMC using an attitude indicator (AI) as their head-down attitude instrument, no head tilt was recorded. Therefore, Patterson deduced that making a transition between the two visual cues also caused a transition in frames of reference.

Although the horizon symbol on the AI did not cause the OKCR, the horizon symbol on the HMD may have a different affect on pilots. The HMD horizon symbol has a larger field of view than the horizon symbol on an AI, and is conformal to the true horizon – the symbol overlays the real-world feature. Therefore, when a real-world feature is not visible, pilots can infer the location of the real-world feature by relying on the location of the symbology representing it. Since previous simulation studies have shown that pilots exhibit the OKCR in VMC (Braithwaite, Beal, Alvarez, Jones, and Estrada, 1998; Gallimore, Brannon, Patterson, and Nalepka, 1999; Gallimore, Patterson, Brannon, and Nalepka, 2000; Patterson, 1995; Smith, Cacioppo, and Hinman, 1997), one could hypothesize that the OKCR will be present when pilots are flying in VMC with the conformal horizon of the HMD symbology visible at the same time as the true horizon. Additionally, if the OKCR is observed with the HMD symbology in VMC, one could hypothesize that the OKCR will also be present with just the HMD symbology in IMC because of the conformal horizon symbol. If pilots do tilt their heads during both VMC and IMC, thus continually using a world frame of reference to maintain orientation, transition problems should decrease. Therefore, the objective of this study was to determine frame of reference (via the OKCR) and task performance during frequent transitions of visual conditions using primary flight HMD symbology and an AI with supporting airspeed and altitude instruments.

## METHOD

### Participants

Eleven rated U.S. military pilots volunteered to participate in this study. Subjects had a minimum of 100 hours of HUD experience, and their average flight time was 1781 hours in various fighter aircraft (F-15, F-16, F-18, and A-10).

### Apparatus

*Hardware*. The experiment was conducted in a fixed-base, single-seat, F-15 type shell with an F-15E stick and throttles. A Matsushita color monitor (21” by 16”) displayed the head-down formats. The simulator also contained three BARCO Retrographics 801 machines that supported a 111_ horizontal by 27_ vertical out-the-window scene. A Kaiser SIM EYE 40 HMD system was used to present attitude symbology. The HMD was binocular, portrayed monochrome symbology, had a 40_ circular FOV with 100% overlap, and 1280 x 1024 resolution. A Flock of Birds 6-D Multi-Receiver/Transmitter Tracking Device was attached to the helmet and measured pilot’s head position.

*Software*. The head-down display suite used for this study consisted of an up-front control unit and three 6X8 multifunction displays (MFDs). The

center MFD contained instruments including the AI, airspeed clock, and altitude clock with incorporated vertical velocity indicator. The HMD symbology consisted of the MIL-STD 1787 HUD Symbology Set (U.S. Department of Defense, 1996), which occupied a 30_ horizontal by 20_ vertical FOV. With the use of the head tracking data, the “virtual HUD” on the helmet acted exactly like a real HUD. The HMD symbology also contained a vertical velocity indicator incorporated with the altimeter.

*Flight profile.* Pilots performed a vertical “S” maneuver for this study (Figure 1). This is a practice maneuver pilots perform to become proficient in instrument flying. The profile contained a series of constant banked, constant rate climbs and descents (commanded vertical velocity of 1000 ft/min) at a commanded airspeed (300 knots). A commanded angle of bank (30_) was maintained during the climb and descent, and the direction of the turn was reversed at the beginning of each ascent and descent. The task started at the commanded minimum altitude of 15,000 ft mean sea level (MSL). At approximately 15,400 ft MSL, the cloud deck began to obscure the real-world visuals with total clouds occurring at approximately 15,600 ft MSL. The commanded maximum altitude was 16,000 ft MSL. The placement of the cloud deck was such that pilots were in VMC for half of the task and in IMC for the other half.

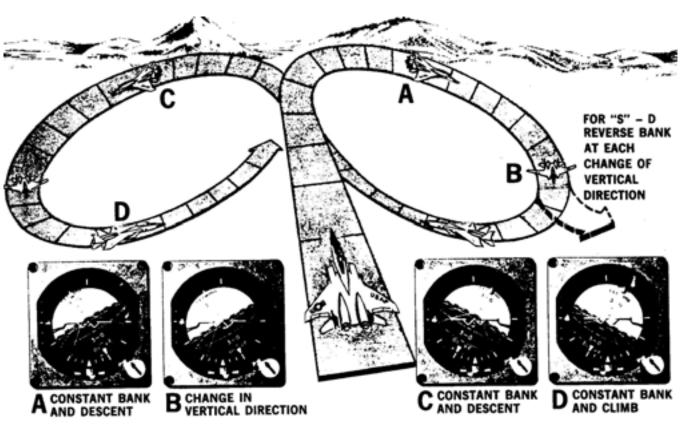


Figure 1. Vertical ”S” maneuver (U.S. Department of the Air Force, 1984).

## Experimental Design

The analysis for this study was divided into two parts. First, the OKCR analysis involved a 14x2x2 within-subjects design with three independent variables and one dependent variable. The three independent variables were: 1) aircraft roll (-35° to +35° in 5° increments excluding 0°), 2) display format (HMD and AI), and 3) meteorological condition (IMC and VMC). The single dependent variable was degree of head tilt.

The second analysis on task performance employed a within-subjects design with a single independent variable and multiple dependent variables. The two levels of the independent variable, display format, were HMD and AI. The dependent measures included root mean square (RMS) error between the commanded values and the actual values of the following parameters: 1) vertical velocity, 2) airspeed, 3) maximum altitude, and 4) minimum altitude.

## Procedure

Participants were briefed on the purpose of the study. After a consent form was signed, a standardized briefing was presented. Pilots received a practice session before the data collection session to allow them to become familiar with the aeromodel characteristics, the symbology, and the data collection task. After data collection, pilots were asked to fill out a questionnaire pertaining to the study.

# RESULTS

The first analysis on the OKCR revealed no statistically significant effects. The main effect for display type showed *marginal* significance ($F(1, 480) = 2.91$, $p = 0.0886$). The average head tilt when using the HMD was 0.07 degrees; average head tilt when using the AI was 0.46 degrees. Given normal head movement in the cockpit, these values have no practical significance.

For the second analysis, to determine if separate ANOVAs or a single MANOVA was appropriate, a correlation analysis was conducted. The variables were not moderately correlated (0.5 – 0.7), and none were highly correlated ($\geq$ 0.8), therefore, all variables remained in the analysis and separate ANOVAs were conducted (Tabachnick and Fidel, 1996). The results are presented in Table 1, and show a significant effect in terms of vertical velocity deviations ($F(1,20) = 7.83$, $p = 0.011$). To

TABLE 1.
ANOVA table for Vertical Velocity

| ANOVA Vertical Velocity | *df* | *SS* | *MS* | *F* | *Sig. F* |
|---|---|---|---|---|---|
| Model | 1 | 214986.5 | 214986.5 | 7.83 | 0.01 |
| Error | 20 | 549105.9 | 27455.3 | | |
| Corrected Total | 21 | 764092.4 | | | |

review correlation coefficients and ANOVA tables of all dependent variables, see Liggett (2000). Average vertical velocity RMS error for the AI was 515.99 ft/min; average vertical velocity RMS error for the HMD was 318.28 ft/min. Therefore, when subjects used the HMD, there were significantly lower vertical velocity deviations than when using the AI. No other dependent variables were significant.

## DISCUSSION

Contrary to the hypotheses, head tilt during this task was negligible. Research has shown that in VMC, when the true horizon is present, the OKCR is also present. This holds true for the limited VMC/HMD/OKCR research conducted to date (Craig, Jennings, and Swail, 2000; Gallimore, Liggett, and Patterson, 2001; Jennings, Gubbels, Swail, and Craig, 1998). For the current study, pilots were in VMC during half of the task. Why then, was the OKCR not present? The reason for this may be related to the nature of the task. In the previous research, when pilots were in VMC, they were performing a task that required them to attend to the real-world visual cues. They were flying low-level ground-oriented tasks, executing maneuvers based on landmarks and waypoints. In contrast, the vertical "S" maneuver was developed to help pilots become proficient with instrument flying. When the HMD symbology was present, regardless of meteorological condition, pilots were concentrating on the symbology to perform the task. Since the majority of the symbology is designed to stay upright at all times (digital readouts, aircraft symbol, bank scale, etc.) pilots may have been keeping their head in an upright position to ensure accurate readability of the symbology critical to their task. One pilot's comment on the questionnaire sums up this point, "I was so saturated with the symbology that flying IMC or VMC made little difference". Due to the fact that the task was instrument intensive, pilots did not need to transition to real-world visual cues. Therefore, the effect of transitions was not fully tested in this study. Although is seems as if it may be possible to eliminate transition problems by making pilots' tasks instrument intensive, this is not realistic in an environment in which pilots utilize the real-world visual scene as much as possible.

The results of the second analysis showed that the only dependent measure with a significant difference was vertical velocity deviations. When using the HMD, pilots had fewer deviations. The reason for this finding is thought to again be related to the task. Pilots were performing a vertical "S" maneuver in which they were to maintain a constant vertical velocity for ascent and descent segments. The vertical velocity indicator for both formats is a curved line that arcs around the altimeter clock. When the arc reaches a specific point, the second dot from the curve's origin for this application, pilots are ascending or descending at 1000 ft/sec depending on which direction the arc is moving (clockwise for ascending; counterclockwise for descending). This task was very instrument intensive, causing the subjects to concentrate on the symbology. The HMD symbology was visible head-up and occupied a 30° horizontal x 20° vertical FOV. The AI was head-down and occupied a smaller FOV (12° horizontal x 8° vertical FOV which includes the AI ball, and the airspeed and altitude clocks). The subjects had to maintain the commanded vertical velocity while maintaining the commanded airspeed and bank angle as well.

There are two reasons why the pilots may have had a harder time controlling their vertical velocity when using the AI. First, it is simply harder to perform such a precise instrument task with a smaller instrument (smaller font, thinner lines) in the head-down position (parallax when interpreting the instrument markings). Second, there were additional cues pilots could have used to determine their vertical velocity in the HMD condition. When pilots used the head-down instrument, they pitched their heads down and never again looked up at the out-the-window scene. The only way they could determine their rate of ascent or descent was to look at that part of the symbology.

When they did a cross check, they would not notice a change in ascent or descent rate until they looked back at the vertical velocity indicator. In contrast, with the HMD symbology, during times when the pilots were in VMC, they could view the rate at which the outside scene changed in the background when they were maintaining the commanded vertical velocity. Then, if they were doing their cross check and noticed the outside world changing at a different rate, they could correct for it more quickly.

## CONCLUSIONS

This study showed that there are advantages to displaying attitude information in a head-up location in terms of maintaining vertical velocity for this type of task. However, due to the nature of the task, it appears as though pilots were not transitioning between the two types of visual cues (real-world and symbology) during the different meteorological conditions. Therefore, the true impact of frequent transitions between visual cues when using HMD attitude symbology was not fully tested. Additional research employing different visual tasks is necessary.

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